Future studies in various phenomena connected with the movements of the Earth's crust may perhaps tend to advance our knowledge respecting the problem of the prediction of great earthquakes which are often preceded by what may be called "fore-shocks." In the mean time and always it will be necessary to build houses and other structures strong enough to resist earthquake shocks.

SAN FRANCISCO, June 26, 1906.

THE LATITUDE OF UKIAH BEFORE AND AFTER APRIL 18, 1906.

BY SIDNEY D. TOWNLEY.

After investigation had shown that the earthquake of April 18th was caused by horizontal shearing along a geological fault running in nearly a straight line from the vicinity of San Juan, in San Benito County, to near Point Arena, in Mendocino County, and that relative displacements along the line of fault had been found, amounting, in one instance at least, to as much as twenty feet, the question naturally arose, Have the latitudes and longitudes of places near the fault-line been disturbed in a measurable degree?

The International Latitude Observatory at Ukiah, where continuous observations for the variation of latitude are made by the writer for the International Geodetic Association and under the superintendence of the United States Coast and Geodetic Survey, is situated about twenty-six miles to the east-northeast of the point where the fault-line enters the Pacific Ocean near Point Arena. That a displacement of a measurable amount could have taken place at that distance from the fault-line seemed highly improbable, but an approximate reduction of all the observations for latitude made on April 16th, 17th, 18th, and 19th showed an apparent displacement of three feet to the south. On account of the small number of observations involved and the approximate nature of the reductions, this apparent shift could not be looked upon as certainly real.

As these computations did not settle the matter one way

or the other, it seemed desirable to make further computations, and consequently all of the observations for latitude, 233 in number, obtained between April 4th and May 4th, both inclusive, have been definitively reduced, and the results are pre-

TABLE I.

	GROUP VI.								GROUP VII.							
Pair . . .	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
1906, April 4	2.31	1.96	1.79	2.15	1.81	2.14	2.25	3.12	1.92	1.95	2.20	1.64	2.41	2.24	1.93	2.31
5	2.24	1.65	1.75	1.93	1.74	2.61	1.87	2.76	2.04	1.86	2.18	1.73	2.15	2.15	2.01	2.27
7	2.25	1.41	2.01	2.37	1.72	2.08	2.01	2.71	2.17	1.73	2.35	1.90	2.24	2.24	2.05	2.60
10	1.93	1.45	1.98	2.02	1.87	2.26	2.03	2.83	2.11	1.89	1.96	1.48	1.88	2.17	2.09	2.36
11	1.57	1.74	1.53	2.29	1.82	2.30	1.92	2.72	2.21	1.97	2.07	1.75	2.24	2.07	1.77	2.55
12	1.98	1.57	1.65	1.99	2.16	2.41	1.95	2.72	1.90	1.92	2.09	1.52	2.23	1.87	1.89	2.35
13	2.15	1.79	1.87	1.90	1.90	2.11	2.17	2.90	2.02	2.27	1.91	1.68	2.11	1.98	2.01	2.32

	GROUP VII.								GROUP VIII.							
Pair . . .	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
1906, April 16	2.18	2.21	2.22	1.72	2.08	2.05	2.27	2.38	1.93	1.85	....	....	....	....	....	....
17	2.01	2.30	2.07	1.92	2.09	1.77	2.28	2.57	2.22	1.80	2.27	1.87	2.00	1.89	2.14	1.87
18	2.05	2.15	2.46	1.89	2.08	2.04	1.87	2.13	2.25	2.53	2.26	1.91	1.80	1.86	2.45	2.19
19	1.97	1.84	2.06	1.76	1.99	2.14	2.06	2.62	2.04	1.79	2.50	1.39	1.66	2.08	2.37	2.15
25	2.04	2.12	2.03	1.38	2.07	1.99	1.66	2.35	2.14	....	2.38	1.67	1.77	2.08	2.08	1.77
30	1.91	2.16	2.39	1.45	2.16	2.19	1.95	2.60	2.08	2.14	2.58	1.48	1.83	1.86	1.95	1.83
33	2.03	2.61	1.86	1.64	2.01	2.11	2.11	2.32	2.18	1.90	2.29	1.91	2.16	1.67	2.14	1.75
34	2.38	1.80	2.28	1.42	1.98	2.31	2.09	2.65	1.84	1.94	2.30	1.71	2.18	2.24	2.12	1.76

sented in Table I, which gives the individual values of the latitude — 39° 8′ 10″. All corrections; level, differential refraction, curvature of the parallel, and progressive errors of the micrometer-screw have been taken into account, and the observations were reduced by means of the declinations furnished by the International Geodetic Association.

A cursory inspection of the results given in Table I shows that the values, especially for certain pairs, are affected by errors of declination of considerable magnitude, and unless steps are taken to eliminate these errors the quantity sought may be completely masked by them. All of the observations for the variation of latitude obtained from the time work began in 1899 to the end of 1905 were made upon the same pairs of stars, and the observations have been reduced with declinations rendered homogeneous by a system of corrections derived from the observations made during the first two years of this time. At the beginning of 1906, however, thirty out of the total of ninety-six pairs were replaced by new ones, and of course a system of homogeneous declinations has not yet been obtained. It will probably be well along in the year 1908 before this can be gotten.

It is obvious from these considerations that a discussion of the results presented in Table I is beset with difficulties, although these are not entirely insurmountable. Four different methods have been used in combining the results, and these are presented under the following heads:—

I. The simplest and most obvious way of eliminating the errors of declination is to consider only those pairs which were observed both before and after April 18th. Group VII, pairs 49 to 56, was observed on nine dates preceding and six dates following April 18th, and the simple means give the following results for the latitude of the zenith telescope:

1906, April 11	39°	8′	12″.070	± 0″.012	72 pairs
1906, April 26	39	8	12 .066	± 0 .019	48 pairs

If we take these results only to hundredths of a second, which is perhaps all we are warranted in carrying, it is seen that they are exactly the same. The probable error of a single determination of the latitude in the first series is 0″.103, in the second 0″.131. The first of these is about normal, and the largeness of the second may be due to the fact that since

there are only six observations of each pair in this series, the computed error is itself somewhat uncertain. It will be noticed that the residuals for pair 50 are abnormally large, which is due in all probability to the fact that the first star of this pair is of the 4.5 magnitude and two magnitudes brighter than the second star of the pair. With the instrument employed, it is extremely difficult, especially when the seeing is not first-class, to make accurate settings upon stars brighter than the fifth magnitude.

II. If we consider only the twenty-six observations made upon April 16th and 17th and the observations of the same pairs on April 18th and 19th, in which case consideration of the known variation of the latitude may be neglected, we have:—

1906, April 16.5	39° 8′ 12″.076	26 pairs
1906, April 18.5	39 8 12 .084	26 pairs

Here again the results are identical if taken only to hundredths of a second. On account of the errors of declination involved, it is not possible in this case to compute probable errors.

III. Pairs 42, 45, 46, 48, 52, 56, 59, and 60 are new ones, introduced at the beginning of 1906. If we leave them out of consideration, the resulting means from the other pairs are:—

1906, April 11	39° 8′ 12″.039	90 pairs
1906, April 26	39 8 12 .050	71 pairs

This result, in almost exact agreement with that obtained under II, is obviously open to the criticism that although the declinations of the pairs used in forming the means *belong* to a homogeneous system, yet they form only a *part* of that system, and if we could include the other pairs of the system the result might be changed in some slight degree.

IV. The three methods thus far employed are all open to the fundamental objection that they do not utilize all of the material at hand. In order to do this a system of corrections to the declinations, or to the values of $\frac{1}{2}(\delta_n + \delta_s)$, must be computed, and for this purpose the following methods were employed.

(a) On each night that a complete set of latitude observations was obtained the mean of the sixteen individual values was taken.

(b) With these means the residuals were formed for the individual observations. These residuals are made up of two parts, the accidental errors of observation and the errors of declination referred to a mean declination system of the two groups involved.

(c) The residuals for each pair were collected and the means taken in order to eliminate the accidental errors, and the results are then the corrections to $\frac{1}{2}(\delta_n + \delta_s)$.

(d) By this process two series of corrections to $\frac{1}{2}(\delta_n + \delta_s)$ for the pairs of Group VII were obtained,—first, the corrections referred to the mean-declination system of the group connection VI-VII, and, second, the corrections referred to the mean-declination system of the group connection VII-VIII. These corrections were found to differ appreciatively, and in order to bring them into one homogeneous system all of the corrections for the pairs in series VI-VII were changed by $-0''.020$ and all of those in series VII-VIII by $+0''.024$, thus making the two series of corrections to the pairs of Group VII fulfill the condition that the algebraic sums of these corrections should be equal. The weighted means of the individual values of the corrections in these two series were then taken as the final corrections to the pairs of Group VII. The following table of corrections was thus found:—

TABLE II.

Pair...	41	42	43	44	45	46	47	48
Corr.	$-0''.019$	$+0''.390$	$+0''.246$	$-0''.050$	$+0''.183$	$-0''.230$	$+0''.014$	$-0''.780$
Pair...	49	50	51	52	53	54	55	56
Corr.	$+0''.007$	$+0''.023$	$-0''.083$	$+0''.386$	$-0''.059$	$-0''.036$	$+0''.054$	$-0''.373$
Pair...	57	58	59	60	61	62	63	64
Corr.	$-0''.018$	$+0''.067$	$-0''.283$	$+0''.372$	$+0''.162$	$+0''.151$	$-0''.111$	$+0''.161$

(e) Applying the corrections of Table II to the results given in Table I we have, taking the means before and after April 18th:—

1906, April 11	39° 8′ 12″.051	138 pairs
1906, April 26	39 8 12 .068	95 pairs

The method of procedure outlined above is to a certain extent empirical, and, especially on account of the small amount of data involved, it is admittedly open to certain criticisms. That the result obtained is in practical agreement with those given by the three preceding methods must be

considered, at least to a certain extent, as fortuitous. No entirely satisfactory discussion of the results presented in Table I can be made until a homogeneous system of declination corrections has been obtained, and sufficient material from which to form such a system will not be at hand for at least two years.

In considering the results obtained under I, III, and IV we must take account of the known variation of the latitude. The earthquake came about seven weeks after a minimum of the latitude at Ukiah, and from the normal curve for the variation of latitude we find that at seven weeks after a minimum the latitude should be increasing at the rate of about 0″.02 in half a month.

Collecting the results we have:—

	Observed variation.	Computed variation.	O − C
I	− 0″.00	+ 0″.02	− 0″.02
II	+ 0 .01	+ 0 .00	+ 0 .01
III	+ 0 .01	+ 0 .02	− 0 .01
IV	+ 0 .02	+ 0 .02	0 .00
Mean,			− 0″.005

If real, this would show a shifting of the observatory one half foot to the south. An inspection of the probable errors given under I shows, however, that this result is less than the probable errors of the quantities from which it is determined.

The computations show, and I think conclusively, that there was on April 18th no shifting of the Earth's crust at Ukiah, at least none of sufficient magnitude to be certainly differentiated from the accidental errors of observation in the most refined method which we have for the determination of latitude. A shifting of four feet, and probably of three, would certainly have been revealed by the observations.

July 6, 1906.